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Report RM-GTR-293



Conservation Assessment of the Sacramento Mountain Salamander

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Cynthia A. Ramotnik



Abstract

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This document synthesizes existing information on the Sacramento Mountain salamander, a terrestrial amphibian endemic to three mountain ranges in southern New Mexico. The salamander is found in mixed-conifer forests primarily on USDA Forest Service lands, within and under decayed logs, and beneath rocks and litter. Because the salamander depends on a moist microhabitat, it is vulnerable to actions that directly or indirectly reduce the amount of moisture available to it. This assessment will assist land managers in making informed evaluations regarding consequences of management decisions and guide them toward a coordinated approach in the context of ecosystem management.

Keywords: Amphibia, Plethodontidae, *Aneides hardii*, mixed-conifer forest, logging, New Mexico

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Conservation Assessment of the Sacramento Mountain Salamander

Introduction

The three salamander species known to inhabit New Mexico include the tiger salamander, *Ambystoma tigrinum*; the Sacramento Mountain salamander, *Aneides hardii*; and the Jemez Mountains salamander, *Plethodon neomexicanus*. Of the three, *A. tigrinum* is the single representative of the family Ambystomidae. While populations in Arizona, Colorado, and Utah have experienced recent unexplained die-offs (C. Carey, pers. comm.), *A. tigrinum* appears to remain stable in New Mexico, where it occurs throughout the state. The other two species, both in the family Plethodontidae, are endemic to distinct New Mexico mountain ranges, primarily on federal lands within the north-central (*P. neomexicanus*) and south-central (*A. hardii*) regions of the state. The close association of these two salamanders with mixed-conifer forests makes them particularly vulnerable to forest-management practices such as logging. *P. neomexicanus* has previously been the subject of both a formal Draft Management Plan and a Memorandum of Agreement between state and federal managers.

In contrast, many of the management strategies for *A. hardii* have never been formally adopted by state and federal managers. This conservation assessment is the first step in a process to facilitate coordination between cooperating federal and state agencies. It summarizes the scientific knowledge of the Sacramento Mountain salamander to assist land managers in making informed evaluations of the consequences of management decisions. The technical knowledge reviewed here was obtained from published and unpublished sources (research reports, agency files) and from discussions with individuals knowledgeable about various aspects of the biology of the salamander.

Administrative Status

The Sacramento Mountain salamander is listed as "threatened" by the State of New Mexico (New Mexico Department of Game and Fish 1996) and "sensitive" by the Forest Service (U.S. Forest Service 1988a). In 1985, the

salamander was placed under review as a potentially threatened or endangered species (Category 2 Candidate Species) under the Federal Endangered Species Act (U.S. Fish and Wildlife Service 1985). Recently, the Fish and Wildlife Service discontinued the Category 2 (C2) status and currently refers to former C2 species as "species of concern" (U.S. Fish and Wildlife Service 1996). Current management efforts for the salamander are coordinated between state and federal managers and are guided by a combination of cooperative agreements, management recommendations, and monitoring protocols. Several of the agreements and protocols have not been finalized or formally adopted in writing. The chronology and details of these efforts are described below and summarized in table 1.

Table 1. Summary of listing and management actions (direct and indirect) for the Sacramento Mountain salamander. Abbreviations for agencies are: NMDGF (New Mexico Department of Game and Fish), USFWS (U.S. Fish and Wildlife Service), and USFS (USDA Forest Service).

Date	Action	Agency
1975	Listed as Endangered (Group II)	NMDGF
1985	Listed as C2 Candidate Species	USFWS
	Interagency Committee established	USFS, USFWS, NMDGF
1986	10-year Lincoln National Forest Plan	USFS
1988	Draft Interagency Agreement (specifies formation of New Mexico Salamander Working Group)	USFS, USFWS, NMDGF
	Listed as Sensitive	USFS
	Amendment to Lincoln National Forest Plan	USFS
1989	First meeting of New Mexico Salamander Working Group	USFS, USFWS, NMDGF
1990	Draft protocol to monitor status of salamander (lists several management recommendations)	USFS, USFWS, NMDGF
1993	Federal Listing of Mex. spotted owl	USFWS
1995	Discontinuation of C2 Candidate Species List	USFWS
1996	Record of Decision for Amendment of Forest Plan	USFS

Following state listing of the Sacramento Mountain salamander in 1975, no formal management action was undertaken by state or federal managers for the next 10 years. In 1985, an Interagency Committee was established, consisting of representatives from the Forest Service, Fish and Wildlife Service, and New Mexico Department of Game and Fish. The goal of this committee was to identify data and management needs for both of New Mexico's endemic salamanders, *A. hardii* and *P. neomexicanus*. In 1988, the committee drafted an Interagency Agreement recognizing management responsibilities of the three agencies, which aimed to eliminate the need for protective status of both salamanders. Once the Agreement was signed by all parties, the Forest Service would suspend "lumbering and associated activities ... in all areas ... occupied by [*Aneides*], in 85% of ... potential occupancy, and in 50% of ... possible occupancy" (Draft Master Interagency Agreement 1988). A final version has been signed only for *Plethodon* (Memorandum of Agreement signed 30 May 1991). No Interagency Agreement for *Aneides* has been developed or signed.

The Draft Interagency Agreement also specified the creation of a "formal salamander task force" to serve in an advisory capacity for the management of *A. hardii* and *P. neomexicanus*. Although the Interagency Agreement has never been signed to "formalize" the task force (now called the New Mexico Salamander Working Group [Group]), the Group has met regularly since its inception in March 1989. In 1990, members of the Group drafted a document including a protocol for monitoring the status of Sacramento Mountain salamander populations and listed several management recommendations. The recommendations specified that, within a 10-year planning period, no more than 25% of the total known occupied salamander habitat can be harvested (logged), and no more than 40% can be harvested within a single planning area. Additional recommendations include leaving all unmerchantable logs over 12 inches diameter in all stand prescriptions, and allowing prescribed burns for site preparation in up to 5% of the occupied habitat. These recommendations have been complied with by the Forest Service since they were proposed, even though the document has never been finalized.

Long-term management goals of the Lincoln National Forest are specified in the Lincoln National Forest Plan (Plan) and are applicable for a 10-15 year period (U.S. Forest Service 1986). The Plan provides some management recommendations specific to *A. hardii*, most or all of which are found within Appendix C ("Forest-Wide Standards and Guidelines for Federal and State Threatened and Endangered Species") and within Plan Amendments (U.S. Forest Service 1988b). Appendix C discourages fuelwood gathering activities within salamander habitat and states that the Forest Service will cooperate with other

agencies to determine the habitat requirements for the Sacramento Mountain salamander (U.S. Forest Service 1986:206). Until habitat requirements are determined, interim guidelines are provided to address slash disposal and winter logging. Interim guidelines are deleted in the Plan Amendment (U.S. Forest Service 1988a) and replaced with a statement that occupied salamander habitat will be evaluated on a "site-specific basis" and addressed through the integrated resource management process (IRM) (U.S. Forest Service 1988b: replacement page 206).

The Lincoln National Forest has an active survey program for Sacramento Mountain salamanders on the Sacramento District and maintains a Geographic Information System database that tracks the amount of acreage surveyed, the amount occupied by salamanders, and the subset of occupied habitat which has been logged. From 1986 to 1992, almost 95,000 acres have been surveyed, revealing that 27% (25,855 acres) is occupied by salamanders. During the current 10-year planning period, the Group's recommendation was met in regard to harvesting "no more than 25% of the total known occupied salamander habitat" (the actual number was 20%, D. Salas, pers. comm.), and no more than 40% was harvested within individual planning units (except in 1987). The Lincoln National Forest is mapping the habitat occupied by salamanders within the Sacramento District.

The Federal listing of the Mexican spotted owl (*Strix occidentalis lucida*) as threatened in 1993 (U.S. Fish and Wildlife Service 1993) has had recent indirect management implications for the Sacramento Mountain salamander, due to the close association of both species with mixed-conifer forest. Restrictions and modifications in resource management activities, such as logging and grazing in designated critical habitat for the owl, have been in effect since the late 1980s. However, the impact of these new restrictions on the salamander has been minimal, since the majority of mixed-conifer forest had been harvested within the Lincoln National Forest by 1986 (D. Salas, pers. comm.). Specific management guidelines for the owl went into effect 15 June 1996 in an amendment to the Forest Plan (U.S. Forest Service 1996). Some of the modifications having potentially beneficial impacts on the Sacramento Mountain salamander include the Forest-wide emphasis on uneven-aged silviculture methods versus even-aged methods, the extension of rotation ages for even-aged stands to greater than 200 years, and the retention of large snags and woody debris within mixed-conifer forest. Revision of the Lincoln National Forest 10-year Plan is scheduled to begin in 1999 (U.S. Forest Service 1996:13) and will provide an opportunity to review the contents of the latest amendment. What impact the revised Plan will have on the Sacramento Mountain salamander remains to be seen.

Review of Technical Knowledge

Systematics

The Sacramento Mountain salamander was discovered in New Mexico in 1940, when the presence of only one other plethodontid salamander, *Plethodon idahoensis*, was confirmed from the "entire Rocky Mountain system" (Lowe 1950:92). The salamander was described from a single, poorly preserved juvenile specimen, and was placed in the genus *Plethodon* (Taylor 1941). Lowe (1950) transferred the species to the genus *Aneides* based on comparison of skeletal features of *Plethodon* and *Aneides*. Sessions and Kezer (1987) examined chromosomal variation within the genus *Aneides* and concluded that *Aneides* has undergone pronounced karyological divergence from a *Plethodon*-like ancestor. Relative to *Plethodon*, *Aneides* demonstrates an increased rate of chromosomal rearrangement.

The genus *Aneides* consists of five species: *A. aeneus* occurs in the Appalachian region of the eastern United States; *A. hardii* is endemic to south-central New Mexico; and *A. ferreus*, *A. lugubris*, and *A. flavipunctatus* extend along the West Coast from Vancouver Island, Canada, to northern Baja California, Mexico. The ranges of the latter three species overlap in northern California. Compared to other members of the genus, *A. hardii* is the most generalized morphologically (Wake 1966) and the most sexually dimorphic (Staub 1989).

Protein comparisons reveal that *Aneides* is most closely related to the western group of *Plethodon*, from which it arose approximately 24-38 million years ago (Larson et al. 1981). Lowe (1950) argues that the distribution of the genus *Aneides* was associated with the transcontinental Arcto-Tertiary Flora until the late Miocene. Subsequent climatic and physiographic changes created large areas of savannah and grassland, isolating members of the genus to the cooler, more mesic (e.g., coastal and montane) areas. Electrophoretic and immunological data suggest that *A. hardii* diverged from other *Aneides* during the mid-Miocene, approximately 20 million years ago (Larson et al. 1981). Using electrophoretic techniques, Pope and Highton (1980) suggest that *A. hardii* separated into the three existing populations (Capitan, White, and Sacramento mountains) during the latter half of the Pleistocene.

Schad et al. (1959) examined geographic variation among the three populations of *A. hardii*. Whereas they noted that the Capitan population was morphologically the most distinct, differences between this population and the other two were not significant enough to warrant subspecific designation. Pope and Highton (1980) found that genetic divergence was small among the three populations.

Description

The Sacramento Mountain salamander is the smallest member of the genus, yet is typical with respect to masseter muscle development, sulci of the head and neck region, body proportions, and prominently overhanging teeth (Lowe 1950). Although habits of the genus range from terrestrial to arboreal, *A. hardii* shares body features typical of the terrestrial members: cylindrical trunk and tail and relatively short limbs and digits (Wake 1966). The tail is slightly shorter than the snout-vent length (SVL), which ranges from 43 to 63 mm in adults of both sexes (Staub 1989). Although males have a shorter trunk than females, they tend to be larger due to the greater head and tail length (Staub 1989). Costal grooves number 14-15 and there are 2 to 4-1/2 costal folds between adpressed limbs (Wake 1965). This monotypic species is light to dark brown on the dorsum with varying amounts of greenish gray to bronze mottling. The venter is light brown, the throat cream-colored. Adult males are easily distinguished from females by the prominent masseter muscles (which give the head a triangular shape) and the presence of a mental gland on the chin. Juveniles may have a brown or bronze dorsal stripe. Staub (1989) provides additional information on skull ossification and body proportions of adults and juveniles.

Geographic Distribution

The Sacramento Mountain salamander is restricted to three disjunct areas within the Capitan, White, and Sacramento mountains of south-central New Mexico in Lincoln and Otero counties (figure 1). Within these areas, salamanders have been found at elevations as low as 2438 m (4 mi NE Cloudcroft, Staub 1986; Scott Able Canyon, D. Salas, pers. comm.), and as high as 3600 m, near the summit of Sierra Blanca Peak (Moir and Smith 1970). Weigmann et al. (1980:33) state that salamanders were collected "from elevations of 7800-7900 ft" (2377-2408 m) but do not provide localities.

Findley (1959) obtained the first specimens from the Capitan Mountains (Lincoln County) in July 1958. Meents (1987) surveyed 42 locations in the Capitan Mountains and found salamanders at 27 of these sites, all above 2682 m. Some of these localities have been surveyed by the New Mexico Department of Game and Fish each year for a number of years (C. Painter, pers. comm.). All known localities within the Capitan Mountains occur within the Capitan Mountains Wilderness, Lincoln National Forest (Smokey Bear District).

The population in the White Mountains (Lincoln and Otero counties) is centered on Sierra Blanca Peak. Salamanders are known from localities to the north and north-

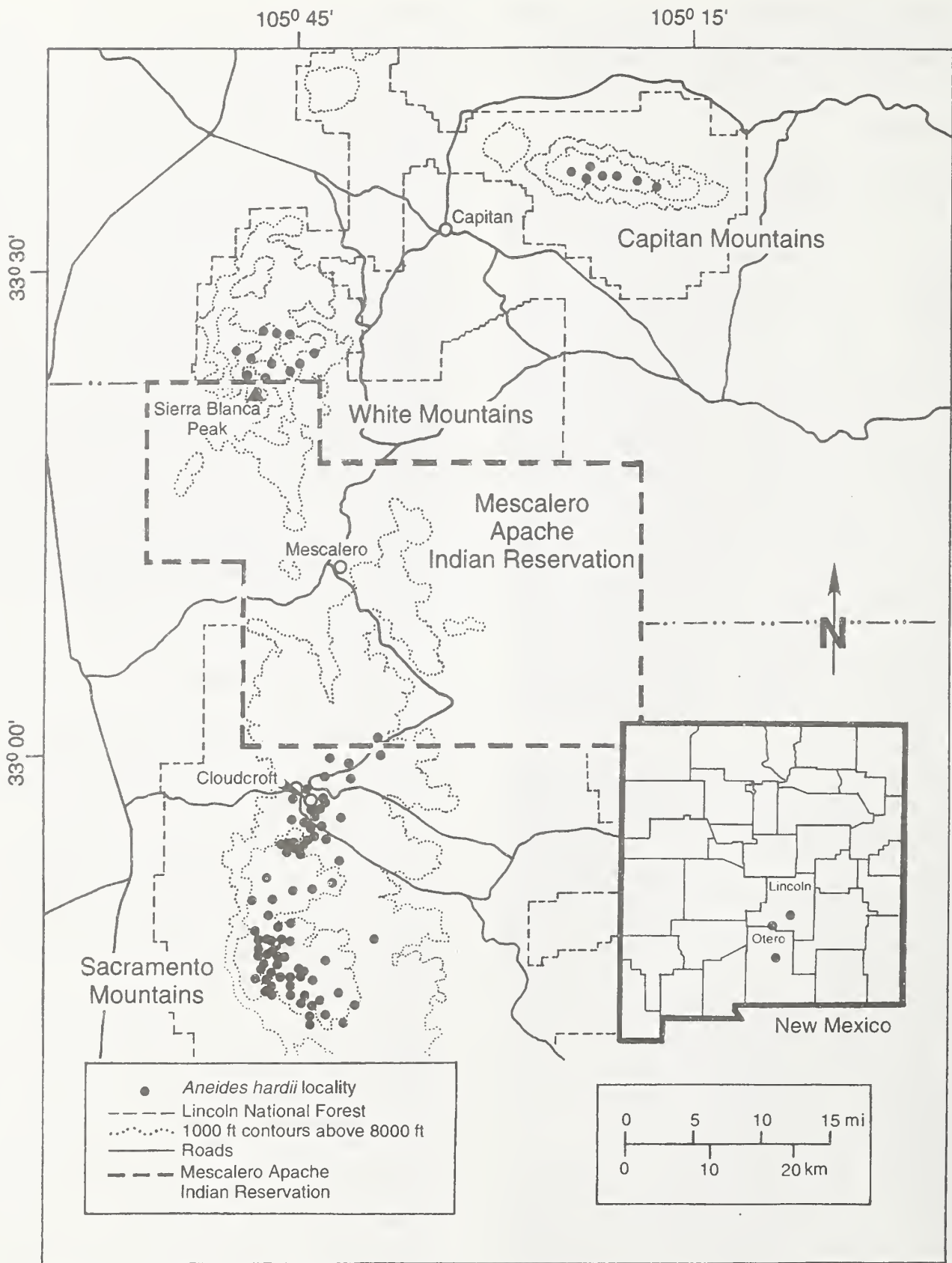


Figure 1. Distribution of the Sacramento Mountain salamander, *Aneides hardii*, within Lincoln and Otero counties, New Mexico.

east, on lands administered by the Lincoln National Forest (White Mountain Wilderness, Smokey Bear District). A single specimen is known from the southern end of the Mescalero Apache Reservation along State Highway 24. Additional specimens have been reported elsewhere on the reservation (N. Jojola, pers. comm.), but precise localities are not available.

The third population occurs within the Sacramento Mountains (Otero County), from the vicinity of Cloudcroft southward to the southern end of the mountain range. This population includes the type locality "Sacramento Mountains at Cloudcroft, 9000 ft" (Taylor 1941). The majority of known salamander localities occur within the Sacramento District, Lincoln National Forest, but a few occur on private lands.

The Capitan population is the most geographically isolated. It is separated from the Sierra Blanca populations by a straight-line distance of 12 miles of unsuitable habitat of pinyon-juniper vegetation (Schad et al. 1959). A weaker barrier occurs between the Sierra Blanca and Cloudcroft populations, where they presumably approach within two to three miles of each other in a narrow band of mixed ponderosa pine, spruce, and fir at 2286 m (within the Mescalero Apache Reservation). Schad et al. (1959:302) hypothesize that "relatively small climatic changes would suffice to reunite the two populations."

Habitat Description

Salamanders are found within mixed-conifer forest above 2400 m (figure 2). The dominant trees within these montane and subalpine forest habitats include Douglas-

fir (*Pseudotsuga menziesii*), white fir (*Abies concolor*), and Engelmann spruce (*Picea engelmannii*). Salamanders are sometimes found in "pure stands of Engelmann spruce" (Johnston and Schad 1959:576). Aspen (*Populus tremuloides*), Rocky Mountain maple (*Acer glabrum*), gooseberry (*Ribes* spp.), and oceanspray (*Holodiscus dumosus*) share the understory with seedling conifers and downed logs in various stages of decay (Scott and Ramotnik 1992). Taylor (1941:77) identifies the habitat of the type specimen as "pine forest" but Lowe (1950) amends this to Douglas-fir based on elevation.

During June-September when salamanders are active on the surface, they are found within and under logs and moist litter, and under rockslides and surface objects such as bark, rocks, and small woody debris. Above timberline, they are associated with rocks and mats of mosses and lichens (Moir and Smith 1970). Whereas salamanders can be found beneath both coniferous and deciduous logs, they are most often found within coniferous logs (primarily Douglas-fir) in advanced stages of decay. The creation of internal channels within the decaying coniferous logs allows salamanders access to a greater portion of the log (figure 3). Weigmann et al. (1980) found no cover preference between juveniles and adults. Although salamanders can be found on slopes at all aspects, they are relatively easier to detect on the surface of more mesic north- and east-facing slopes. Because salamanders are absent from the surface during much of the year (they spend about eight months below the soil surface, Scott and Ramotnik 1992), they must be using other habitat components as well.

Several studies examined the habitat affinities of *A. hardii*. Meents (1987:2) studied the Capitan population and found that salamanders tended to occur on north- and

Figure 2. Habitat of the Sacramento Mountain salamander within the Sacramento Mountains, New Mexico. The mixed coniferous forest includes Douglas-fir, white fir, and Engelmann spruce. Salamanders are found within and under the decayed logs. Photograph by C.A. Ramotnik.





Figure 3. Well-decayed Douglas-fir log showing the internal channels where Sacramento Mountain salamanders can be found. Photograph by C.A. Ramotnik.

east-facing slopes and were found only "beneath or within logs, or under the bark of logs." Elsewhere, salamanders could be found in areas with a high canopy cover "if appropriate logs were also present" ("appropriate logs" consisted of Douglas-fir in an advanced state of decomposition). Weigmann et al. (1980) studied the Sacramento Mountains population and concluded that salamanders were more often found in stands where either Douglas-fir or white fir or both predominated, but that the composition of the shrub layer also affected their abundance. Salamanders were more frequently associated with an understory of Rocky Mountain maple, less frequently with a sparse understory, and rarely with Gambel oak. In addition, salamanders were found on transects with steep slopes (\bar{x} = 24%); high elevations (\bar{x} = 2739 m), and high overstory cover (\bar{x} = 71%) and ground story cover (\bar{x} = 66%). Ramotnik and Scott (1988) developed a discriminant model to predict salamander occurrence. The variables with the best predictive value were high elevation; large numbers of Engelmann spruce, white fir, and Douglas-fir; and large downed logs. Salamanders were negatively correlated with the presence of pine.

General Ecology

Relationship With Environment

The physiological interaction of amphibians with their abiotic environment is a complex, dynamic system of related processes. Because they are ectotherms with a permeable body covering, terrestrial plethodontid salamanders such as *A. hardii* had to evolve adaptations to

cope with the inevitable loss of body water while maintaining a moist skin for gas exchange. This has been made possible through a combination of many unique behavioral responses.

Because *A. hardii* is lungless, gas exchange occurs primarily across moist skin. To minimize evaporative water loss, most terrestrial amphibians are nocturnal, avoiding higher daytime temperatures and lower atmospheric humidity (Duellman and Trueb 1986). The use of diurnal retreats such as logs and the undersides of rocks, where humidity is higher, allows them to rehydrate when necessary. Although the extent to which *A. hardii* is nocturnal is unknown, the use of diurnal shelters is commonly reported. *A. hardii* is rarely, if ever, seen active away from cover and, if so, only during or after summer rains (pers. obs.). Laboratory humidity preferences for *A. hardii* are high and range from 54.5 to 97.2° C (\bar{x} = 83.2° C; Carey 1988). The salamander can survive an average water loss of 28.2% (range = 26.5 to 31.3%) of its body mass (Carey 1988), which is lower than that reported for other amphibians (Thorson and Svihla 1943). To reduce the amount of surface area exposed to evaporation, salamanders may curl their bodies and tails (Ray 1958), or form aggregations of two or more animals (Duellman and Trueb 1986). Clumping or aggregating has been observed for the Sacramento Mountain salamander and is more likely to occur in drier or less suitable habitats (Weigmann et al. 1980). Chris Borg (pers. comm.) observed clumping behavior more often in "cut patches" and noted a greater frequency of clumping behavior in 1995 versus 1996, which he speculates could be associated with lower rainfall in 1995. Small salamanders have greater rates of water loss than larger salamanders due to the greater proportion of surface area exposed.

Field temperatures of temperate terrestrial plethodontids range from -2.0 to 26.3° C (\bar{x} = 13.5° C; Brattstrom 1963; Feder et al. 1982) and typically reflect the temperature of their immediate surroundings, especially the substrate (Duellman and Trueb 1986). Field temperatures of 390 cover objects in which *A. hardii* was found ranged from 8.0 to 18.0° C (\bar{x} = 11.4° C, Williams 1978). The preferred body temperature of *A. hardii* (defined as the mean value of the range of temperatures within which an organism is voluntarily active; Bogert 1949) is 11.3° C (range=6.1 to 15.9° C; Carey 1988) and is lower than that reported for 13 species of eastern terrestrial salamanders (Spotila 1972). Using the critical thermal maximum (CTM) as a measure of temperature tolerance of an organism where 50% survive, Whitford (1968) and Carey (1988) showed the CTM of *A. hardii* to be 33.3° C and 30.8° C, respectively. This is significantly lower than for terrestrial eastern plethodontids but is comparable to species inhabiting cold mountain streams in the eastern United States (Whitford 1968). The low thermal preferences and CTM most likely reflect adaptations by *A. hardii* to the low temperatures characteristic of the microclimate of its habitat.

The standard metabolic rate (maintenance costs) of *A. hardii* is low, yet comparable to that of other plethodontid salamanders at equivalent temperatures, and is consistent with an ecological strategy of a low-temperature, low-energy utilization lifestyle (Carey 1988). Metabolic costs are higher at higher temperatures and, based on laboratory results, would be expected to increase 2.8-fold between 5 and 15° C and 3.5-fold between 15 and 25° C (Carey 1988). Whitford (1968:250) suggests that temperatures around 15° C may represent an "environmental optimum" for *A. hardii*, based on measurements of oxygen consumption and heart rate at different temperatures.

Food and Feeding

A. hardii feeds on ground-dwelling invertebrates, primarily arthropods in classes Arachnida and Insecta, some molluscs (Johnston and Schad 1959; Staub 1986), and earthworms (Scott 1990). Johnston and Schad (1959) examined the stomachs of 16 salamanders and found the following: 40% ants, 28% adult and larval beetles, 10% spiders, 8% *Acarina*, and 4.5% Mollusca. Scott (1990) examined the stomach contents of approximately 50 *A. hardii* and found an average of 21 food items from a wide variety of small arthropods, snails, earthworms, and isopods. Males and females exhibit little difference in the sizes of prey taken (Staub 1989).

A. hardii forages aboveground within and under logs, and under rocks and litter, where the majority of prey are found. Scott and Ramotnik (1989) examined arthropod density in soil pits and found few arthropods below the litter layer. Those found within the soil profile occurred down to 35 cm; only earthworm activity was extensive, as evidenced by the presence of castings extending to bed-

rock. Captive *A. hardii* initially foraged during daylight hours, but after acclimation they actively foraged at night or under low-light conditions (Johnston and Schad 1959). Prolonged droughts or periods of low humidity can restrict surface foraging, forcing salamanders belowground where prey are limited.

Ambient temperature has a direct influence on the digestive efficiency of salamanders. At lower temperatures, digestive efficiency increases because food remains in the digestive tract longer than at warm temperatures (Bobka et al. 1981). The increased processing time at lower temperatures is also advantageous when consuming prey containing large amounts of chitin (e.g., adult beetles and ants), which is undigestible by most amphibians except salamanders (Carey 1988). Feder (1983) suggests that plethodontid salamanders have a profound resistance to starvation, due to low metabolic rates and relatively large energy reserves, enabling them to survive indefinite periods between feedings.

Plethodontids probably use visual cues to detect moving prey but rely on olfaction for immobile prey (David and Jaeger 1981). This is strongly inferred by the presence of specialized chemoreceptors called nasolabial grooves (Brown 1968). Although some plethodontids can extend their tongues at distances equal to 44-80% of their body length to capture prey (Duellman and Trueb 1986), *A. hardii* has a relatively short tongue that can be extended usually less than 5 mm (Johnston and Schad 1959). This difference in tongue length may correlate with how various prey are detected and consumed.

Enemies and Defense

Parasites. The following information is taken from Johnston and Schad (1959), who conducted the only study of parasites of *A. hardii*. A sample of 30 adult salamanders collected in July showed a high infection rate, 83% and 90%, by two species of nematodes (roundworms), *Oswaldocruzia* sp. and *Thelandros* sp., respectively. Salamanders examined in September all had parasites and thus probably carried nematodes with them into their winter retreats. Judging by the high incidence of immature parasites in July, the authors speculated that salamanders lose their worms during the winter (due to inactivity that presumably prevents ingestion of infective stages) reacquiring parasites at or near the ground surface each spring.

Predation. Garter snakes (*Thamnophis elegans*) are the only known predators of the Sacramento Mountain salamander (N. Scott, pers. obs.). Other snakes (e.g., *Diadophis punctatus*, Duellman and Trueb 1986), passerine birds (Jaeger 1981), and nocturnal mammals (e.g., raccoons, skunks, and shrews, Duellman and Trueb 1986) are reported to prey on plethodontid salamanders elsewhere and may opportunistically consume Sacramento Mountain salamanders.

Antipredator mechanisms. Brodie (1983) listed 29 antipredator mechanisms in terrestrial salamanders, including nine observed in at least one species of *Aneides*. Although not mentioned in this list, adult Sacramento Mountain salamanders are able to spin or writhe in a continuous motion when held in hand (pers. obs.). This behavior could make it difficult for a predator to get a firm grip on the salamander and even cause it to release the prey.

Population Biology

Growth rates. Using marked salamanders, Staub (1986) found that the smallest size class in July grew 5 mm over the summer, while adults (≥ 43 mm SVL) grew 3.2 mm per year (assuming four months of growth per year and that growth rate continues to decrease with age). Staub postulated that it would take a hatchling of 13 mm SVL approximately four years to reach sexual maturity (43 mm SVL). In contrast, information on captive Sacramento Mountain salamanders indicates they can grow up to 8 mm in one month, suggesting that a juvenile (35 mm SVL) could grow to adult size (43 SVL) in one summer (Weigmann et al. 1980). The diet of these captive salamanders is unknown, but if they fed on a richer or more regular food source than wild salamanders, their growth rates could be expected to be greater.

Life span. Staub (1986) calculated that the largest salamanders (>60 mm SVL) were at least 10 years of age, assuming a growth rate of 3.2 mm per year. On the basis of records for captive individuals, some salamanders can live for three to four decades, but known ages for various captive plethodontids are up to 20 yrs (Snider and Bowler 1992).

Population density. The few density estimates available for *A. hardii* are variable and derived from surface searches of the Sacramento Mountain population. No variance estimates are available, but Weigmann et al. (1980) indicate that standard deviations are large. Weigmann et al. (1980) and Ramotnik and Scott (1988) computed density estimates of $0.001/\text{m}^2$ and $0.006/\text{m}^2$, respectively. Staub (1986) provided density estimates for three populations ranging from $0.38/\text{m}^2$ to $1.12/\text{m}^2$. Several factors could explain these variations. For example, Weigmann et al. (1980) found few juveniles, which would underestimate density. Ramotnik and Scott (1988) averaged the results (range = 1-41 salamanders) from sites that varied considerably with respect to slope, aspect, and elevation. In contrast, Staub's highest density estimate came from a mature forest, which had not been logged since the early 1900s.

While densities of local populations of plethodontid salamanders vary greatly, estimates for *A. hardii* are not inconsistent with those for other plethodontids (table 2).

Table 2. Estimated densities of populations of plethodontid salamanders using a variety of census techniques (modified from Duellman and Trueb 1986).

Species	Individuals/m ²	Reference
<i>Aneides aeneus</i>	0.2500-0.1000	Gordon (1952)
<i>Aneides lugubris</i>	0.4051-0.4989 ^a	Anderson (1960)
<i>Aneides hardii</i>	0.001	Weigmann et al. (1980)
<i>Aneides hardii</i>	0.006	Ramotnik and Scott (1988)
<i>Aneides hardii</i>	0.38-1.12	Staub (1986)
<i>Ensatina eschscholtzi</i>	0.1482-0.1729	Stebbins (1954)
<i>Plethodon cinereus</i>	0.0496	Test and Bingham (1948)
<i>Plethodon cinereus</i>	2.3670-2.5830 ^b	Burton and Likens (1975)
<i>Plethodon glutinosus</i>	0.0040	Gordon et al. (1962)
<i>Plethodon glutinosus</i>	0.4180-0.8440	Semlitsch (1980)

^a Island populations.

^b Minimal estimates.

Population density estimates are dependent on many factors, including search methodology, local weather conditions, available resources, and variation in predatory pressures (Duellman and Trueb 1986). Additionally, because only a small proportion of the salamander population is on the surface at any time, density estimators can underestimate local populations. Test and Bingham (1948) and Taub (1959) showed that surface census plots gave unreliable total population estimates because they represent only those salamanders found in the top layer of soil. Furthermore, Taub (1961) estimated that only 2 to 32% of the population in the top 2.5 cm of soil is likely to be included in a surface census.

Sex ratio. Plethodontid salamanders are typical of most amphibians in that they have an initial 1:1 sex ratio (Duellman and Trueb 1986). The ratio can change due to differential survivorship of males and females, and timing relative to the breeding season. The sex ratio of *A. hardii* is 1:1 in July, and by September there is a four-fold increase in females on the surface (0.28M:1F; Staub 1986). Because females remain with their eggs until hatching, they are less common on the surface between July and September. After the eggs hatch, females are able to forage on the surface, and their numbers dramatically increase. At the same time, numbers of males decrease at the surface as they begin to retreat to subterranean cavities in September. Johnston and Schad (1959) pooled a sample of three populations of *A. hardii* for July through September, reporting an even sex ratio for the three-month period.

Because the data were pooled, it is impossible to discern monthly differences in the sex ratio.

Age ratio. At most times, the *A. hardii* population consists primarily of adults. Hatching occurs between August and September, at which time the proportion of juveniles increases. Staub (1986) reported 32% juveniles in the July sample, but this doubled in September (66%) as newly hatched salamanders appeared on the surface. Weigmann et al. (1980) found a low proportion of juveniles (6%) on the surface but do not indicate the month. Juveniles are difficult to detect due to their ability to blend with the substrate and, thus, can easily be underestimated in the population.

Movements and Territoriality

Activity. Sacramento Mountain salamanders begin to appear regularly on the surface in June and have been reported on the surface as early as 15 May (D. Salas, pers. comm.). Surface activity occurs throughout the summer months, which is the period of greatest precipitation (July and August). Unless otherwise noted, the following information is generalized for *A. hardii* from a variety of studies on plethodontid salamanders (see Heatwole 1962, Jaeger 1980, Keen 1984, Pauley 1978, Ramotnik 1988). During short periods of drought, salamanders move horizontally along the surface, retreating beneath surface objects (e.g., rocks, logs, sticks) or within litter, where humidity is greater and prey are abundant. During longer periods of drought, salamanders move vertically, either within large decayed logs, or to subterranean retreats. Salamanders respond to decreased temperature and precipitation in September by reducing their surface activity. By October they have retreated to subterranean sites, where they are presumed to be inactive throughout the winter (Johnston and Schad 1959), remaining there until more optimal temperatures and/or levels of moisture occur the following spring.

Because few field observations of salamanders have been reported, the evidence for nocturnal activity in the Sacramento Mountain salamander is scanty. Johnston and Schad (1959:578) observed captive *A. hardii* to be active only at night (following a period of acclimation) and speculated that this pattern was "probably typical ... under natural conditions." More recently, several researchers studied salamanders in the field and reported that nocturnal sampling is unproductive. Weigmann et al. (1980) found a single salamander from 24 transects during nocturnal surveys and suggest this is due to the cryptic coloration of the salamander. Norman Scott (pers. comm.) conducted several searches at night, finding few salamanders. Because of the strong association between surface activity and precipitation, Scott hypothesized that most nights are probably too dry and cold for salamanders. Similar results have been reported by Burton and Likens

(1975), who noted that the eastern plethodontid, *Plethodon cinereus*, is active on the surface on rainy nights.

Movements. Staub (1986) recorded the movements of 15 marked salamanders, reporting that they moved an average of 22.7 m (range=0-50 m) between July and September. Because observations were not made at shorter, more regular intervals, there is no information available on daily or weekly movements, or on home range size. Movements of the Jemez Mountains salamander were studied by Ramotnik (1988) using radioactive isotopes. With few exceptions, salamanders moved infrequently and traveled short distances. Whereas several studies have reported a significant correlation between movements of salamanders and precipitation (Barbour et al. 1969; Kleeberger and Werner 1982; MacCulloch and Bider 1975; Semlitsch 1981), no correlation was found between movements of Jemez Mountains salamanders and precipitation. However, aboveground occurrence decreased as ambient air temperature increased, until a point above 20°C when no salamanders were found at the surface (Ramotnik 1988). *A. hardii* may respond similarly to the Jemez Mountains salamander with respect to movement patterns, differing perhaps only in regard to microhabitat preferences.

Territoriality. Interspecific competition is unlikely within the range of *A. hardii*, since the only salamander that occurs sympatrically, *Ambystoma tigrinum*, has distinctly different microhabitat preferences. Conspecific interactions are likely between males, between brooding females and males, and between juveniles and adults. Staub (1989, 1993) studied agonistic behavior of four of the five species of *Aneides* using scarring frequency as an index of agonistic interactions. The frequency of scarring in *A. hardii* was significantly lower than those three other western species. Sexual dimorphism was less pronounced in the three western species; both males and females showed jaw muscle hypertrophy, and consequently, dimorphism in head size was reduced. This suggests that social selection has been an important force in the evolution of derived morphology and reflects selective pressures for more efficient and intense aggressive behavior in both males and females (Staub 1989).

Reproductive Biology

Reproductive Strategy

The Sacramento Mountain salamander demonstrates a reproductive strategy often termed "K selection" (Williams 1976). This strategy is generally associated with a stable environment that predicts late maturity, multiple clutches, fewer but larger eggs, parental care, and intermittent reproductive effort, all of which are life history attributes of *A. hardii*.

Courtship and Mating

The following information is generalized for the family Plethodontidae; any modifications for *A. hardii* are noted where appropriate. Reproductive activity is induced by warming temperatures in late spring. Courtship takes place underground in June and involves a tail-straddling walk by the male, a behavior unique to plethodontid salamanders (Arnold 1977). Secretions from the well-developed mental gland of the male are transferred to the female via rubbing; in some species the protruding premaxillary teeth of the male are used to assist this transfer (Duellman and Trueb 1986). During the tail-straddling walk, the male deposits a spermatophore that is picked up by the female and stored in the spermatheca, a series of tubules located at the roof of the cloaca. The sperm remain in the spermatheca until ovulation occurs; fertilization is internal.

Sexual maturity is reached at 43 mm SVL, when females are four years of age (based on growth-rate estimates by Staub 1986). Williams (1976) reports that females reach sexual maturity between two and three years of age but do not oviposit for another year to allow the ova to reach sufficient size. Oviposition is asynchronous within the population, occurring between July and September every third year in individual females. Males gorge at the end of August in order to provide energy for spermatogenesis over the winter. Sperm is probably transferred to the vasa deferentia in late fall or winter and stored for spring mating (Williams 1976).

Eggs and Development

The clutch size for *A. hardii* is the lowest of any North American plethodontid salamander. Numbers of eggs range from 1-10, with an average of 5.9 eggs per clutch (Staub 1986). Clutches have been found from mid-July to September (table 3), usually within large, decaying Douglas-fir logs or stumps. The low numbers of clutches

Table 3. Clutch sizes of *Aneides hardii* (modified from Staub 1986).

Number of clutches	Number of embryos	Month found	Reference
4	1,4,4,6	July	Johnston and Schad (1959)
3	3,5,10	July	Staub (1986)
1	3	August	Lowe (1950)
1	10	August	Schwartz (1955)
1	6	August	Weigmann et al. (1980)
9	3,5,5,5,6,7,9,10,10	September	Staub (1986)

detected suggests that many may be oviposited belowground. Eggs are light yellow and suspended by pedicels, which are often intertwined like a cluster of grapes. Females stay with the eggs until the embryos hatch in late August or early September. Maternal care provides protection from predators, reduced risk of fungal infection, and enhanced aeration and/or prevention of adhesive malformation via periodic rotation of the eggs (Duellman and Trueb 1986). Females probably do not actively forage while guarding eggs, feeding only opportunistically. A food-habits study found brooding females with little or nothing in their stomachs, and relatively few females on the surface relative to males (Johnston and Schad 1959). Weigmann et al. (1980), describing a clutch hatched in captivity, report that newly emerged Sacramento Mountain salamanders measured 11-13 mm (SVL) and had color patterns similar to adults.

Threats to Survival

Logging

Because terrestrial salamanders require a moist microhabitat for cutaneous respiration, factors reducing the amount of moisture available to them can have immediate negative impacts. Timber harvest reduces or eliminates the canopy cover, resulting in increased insolation, higher soil and air temperatures, and lower relative humidity. Soil disturbance due to logging equipment and the increased networking of roads (and subsequent traffic on those roads) causes soil compaction, increased erosion (particularly on steep slopes), nutrient losses, and an ultimate decrease in litter depth and moisture.

Three studies examine logging impacts on the Sacramento Mountain salamander. The first was completed by Staub in 1986; two others are ongoing. Whereas no logging studies have been conducted on the Capitan or White mountains populations, Meents (1987) hypothesizes that numbers of salamanders are highest in the eastern part of the Capitan Mountains due to the combined impacts of fire and logging in the western part after 1950, which reduced habitat quality for the salamander.

Staub (1986) compared habitat characteristics and salamander abundance along transects (50 m x 1 m) at three sites within Atkinson Canyon; one site was a control and two had been logged (cable- and tractor-logged) a few years before the study. A second control was located several miles away in an undisturbed area of "prime salamander habitat" in Brown Canyon (Staub 1986:5). No salamanders were found on the logged sites, while numbers of salamanders (averaged from three randomly selected transects per site) on the controls varied from 6.3 (Atkinson) to 18.7 (Brown). Logged sites had significantly higher soil and air temperatures, less ground and canopy

cover, and fewer large, well-decayed logs than did unlogged sites. The best predictors of salamander presence and abundance were soil and air temperatures, and percent ground cover. Due to the absence of salamanders on the two logged sites, Staub (1986) concluded that logging is detrimental to them and should be conducted in patches, leaving large, undisturbed areas (minimum of 0.5 mi²) for salamanders.

In 1986, researchers from the U.S. Fish and Wildlife Service established the first of 25 permanent plots as part of a multi-year, Forest Service-funded monitoring study (U.S. Fish and Wildlife Service 1986). Experimental plots were logged over the span of four years (1986-1990), and post-logging data are now available for up to 10 years on some plots. Since 1986, with the exception of two years, the 19 experimental and six control plots have been monitored annually, via time-constrained searches (Campbell and Christman 1982). Although rigid limits were not imposed on the size of the area searched, the searches covered an area 200-400 m² in diameter. With the exception of one plot, there is considerable yearly variation in

the numbers of salamanders on logged and unlogged plots (table 4), with no trends discernible. The mean number of salamanders per plot on both logged and unlogged plots also varies somewhat across years, though when the ratio of these means is computed as a comparison of salamander abundance, the numbers appear to remain roughly constant from year to year (table 5). An exception is one cable-logged plot (BR3) located on the steepest slope of any permanent plot. Pre-logging numbers of salamanders on this plot were the highest of all plots, but post-logging numbers declined steadily over a seven-year span, from a high of 52 (1986) to a low of 10 (1994). This trend was reversed in 1995 when numbers of salamanders were comparable to those from the 1988-1989 season (Ramotnik 1996).

While the trend in salamander abundance on the permanent plots appears to be somewhat stable, there is a disconcerting trend regarding the distribution of size classes of salamanders. In three of the last four monitoring sessions, juveniles salamanders made up a significantly smaller proportion of all salamanders on logged plots (Ramotnik,

Table 4. Number of *Aneides hardii* found on permanent study sites before and after logging, 1986-1996, on the Lincoln National Forest, Otero County, New Mexico. BR=Brown, TU=Turkey, HA=Harris, MO=Moore, and SA=Scott Able. Sites were cable-logged (LC) or tractor-logged (LT) after the salamander count in one year and before the next count. Dashed lines indicate that searches were not conducted.

Site	1986	1987	1988	1989	1990	1992	1994	1995	1996
BR 1	20 ^b	--, LC	9	19	16	19	10	20	11
BR 2	26 ^b	--, LC	15	15	8	19	28	22	21
BR 3	52 ^b	--, LC	41	31	23	20	10	36	23
BR 4	14 ^b , LT	14	15	34	57	59	50	71	47
BR 5	8 ^b , LT	6	24	34	12	20	37	61	41
BR 6 ^a	--	9	10	20	7	40	39	51	32
BR 7 ^a	--	10	28	41	55	40	42	56	62
TU 1	--	14, LT	20	19	41	26	41	32	22
TU 2	--	28, LT	14	23	34	32	45	28	47
TU 3	--	10, LT	9	24	8	29	32	20	22
TU 4	--	31	25, LT	34	20	129	59	28	46
TU 5 ^a	--	--	38	88	92	105	77	58	69
HA 1	--	--	31	41, LT	12	17	41	24	66
HA 2	--	--	24	29, LT	6	26	34	24	30
HA 3 ^a	--	--	36	43	17	49	52	34	49
HA 4	--	33	--	44, LT	15	40	43	36	35
HA 5	--	--	--	49, LT	27	48	82	44	65
MO 1	--	--	--	0, LT	0	3	0	0	1
MO 2	--	--	--	5, LT	1	4	1	0	0
MO 3	--	--	--	9, LT	1	8	8	4	3
MO 4 ^a	--	--	--	3	2	7	7	5	4
SA 1	--	--	--	--	11, LT	9	2	3	3
SA 2	--	--	--	--	23, LT	20	20	20	13
SA 3 ^a	--	--	--	--	17	16	19	7	14
SA 4	--	7	--	--	17, LT	8	10	9	5

^a Control site.

^b Number of salamanders extrapolated to 2-hour equivalent based on a 1-hour search.

Table 5. Trends in salamander abundance in time-constrained searches on logged and unlogged plots, 1986-1996, Lincoln National Forest, Otero County, New Mexico.

	1986	1987	1988	1989	1990	1992	1994	1995	1996
Logged sites									
Number of plots	--	2	8	9	16	19	19	19	19
Salamanders/plot (\bar{x})	--	10.0	8.4	25.9	17.6	28.2	29.1	25.4	26.4
Unlogged sites									
Number of plots	5	8	7	12	9	6	6	6	6
Salamanders/plot (\bar{x})	24	17.8	27.4	31.0	26.8	42.8	39.3	35.2	38.3
Salamanders/plot (\bar{x})									
Ratio logged/unlogged	--	0.56	0.67	0.84	0.66	0.66	0.74	0.72	0.69

unpubl.). If we assume that the proportions of different size classes are sampled equally well in logged and unlogged plots, then these data suggest that populations on logged plots produce fewer young in some years. The lower reproductive rates or lower survival rates of eggs, hatchlings, or juvenile salamanders observed on logged plots could indicate that logged plots represent less than optimal habitat.

A third logging study was initiated in 1995 by Chris Borg, of New Mexico State University. His two-year study will examine the demographic structure of salamander populations in relation to temperature, moisture, and relative humidity in logged and unlogged sites. Preliminary data indicate that salamanders are found on sites logged within the last 10 years, often in aggregations of up to five individuals, and that within logged sites, salamanders occur under substrates with temperatures above the salamander's preferred maximum (C. Borg, pers. comm.). Due to the increased ecological and energetic costs associated with higher temperatures, salamanders may not be able to maintain their metabolic requirements. The synergistic effects of low humidity and high temperature are likely to result in hydric and thermal stresses whose impacts, if any, remain unknown.

Logging is the primary threat to the Red Hills salamander (*Phaeognathus hubrichti*) in Alabama and is implicated in declines of 29 other species of woodland salamanders (Scott and Ramotnik 1992). Despite differences in methodologies, geography, and harvest prescriptions, the results of numerous studies (Aubry et al. 1988, Bury and Corn 1988, Bury and Martin 1973, Pough et al. 1987), as well as two of the three logging studies on *A. hardii* mentioned above, show that salamanders are not eliminated from logged sites after several years. Whether or not this makes populations more vulnerable to other threats (i.e., drought, fire) is currently unknown. The absence of salamanders on logged plots in Staub's study (1986) could be a sampling artifact arising from the use of relatively narrow transects, resulting in the detection of consistently

fewer salamanders than in time-constrained searches (pers. obs.).

Fire

While generalizations about the effects of fire are made difficult by variables such as fire intensity, size, and behavior, it is known that fire alters vegetation structure and composition, reduces litter depth and other surface features, and modifies the soil chemistry (e.g., pH, mineral content). The most dramatic effects occur during severe, stand-reducing fires that eliminate canopy cover and create younger seral stages. The return of conifer species can require considerable time. In the White Mountains of New Mexico, the return to coniferous trees takes 15-20 years under the most favorable conditions (Hanks and Dick-Peddie 1974).

Although the effects of fire on the Sacramento Mountain salamander have not been assessed directly, some information is available from the Danley Burn, an intense fire that occurred in 1967 within the range of the Sacramento Mountain salamander. Salamanders were not known specifically from the area before the fire but can be predicted to have occurred there based on elevation and tree composition (D. Salas, pers. comm.). An examination of soil pits dug in 1989 on slopes at the edge of the Danley Burn revealed shallow soils that were poorly stratified and well mixed with rocks probably due to sheet erosion following the fire. During the study, salamanders were found in logs far into the Danley Burn (N. Scott, pers. obs.).

Short-term survival of *A. hardii* following a fire is conceivable due to the salamander's ability to retreat belowground to avoid inhospitable surface conditions. In the long term, however, the paucity of prey beneath the surface and the elimination of litter on the surface (where the majority of prey are found) would hinder the salamander's ability to obtain enough energy to support its metabolic requirements. The extent to which *Aneides* can migrate horizontally to more hospitable conditions is unknown, though any extended moves would incur increased metabolic costs.

Grazing, Pesticides, Insects, and Disease

Public issues of management concern to the Lincoln National Forest include grazing, plus prescriptions to control invasive weeds, western spruce budworm, and dwarf mistletoe (U.S. Forest Service 1986). Grazing occurred historically at much greater levels within the range of *Aneides* than it does today (D. Salas, pers. comm.). Before the 1940s, there were approximately 20,000 sheep and a minimum of 20,000 cattle on the Sacramento District alone. The current 10-year plan calls for permitted livestock use of 147,000 AUM (=12,250 animals) Forest-wide, though grazing capacity is expected to increase through "improved management and additional structural and nonstructural range improvements" (U.S. Forest Service 1986:161). The primary detrimental effect of grazing is compaction of soil, which may destroy subterranean passages for salamanders. Grazing is not likely to occur in areas containing dense forest, abundant downed timber, or moderate to steep slopes, which are associated with salamander occurrence.

Whereas the effects of pesticide applications may be detrimental to larvae of aquatic amphibians (Berrill et al. 1993, 1994, 1995), information on potential adverse effects on terrestrial amphibians such as *A. hardii* is nonexistent or anecdotal. Considerations for pesticide application within the range of *A. hardii* include timing of the application, presence of buffer zones, length of time necessary for degradation of the pesticide, and potential for subsequent bioaccumulation within salamanders or their prey (Ramatnik, in letter to U.S. Forest Service, 11 December 1995).

Prescriptions designed to control destructive insects and disease organisms include prescribed burns, selective timber removal, and spraying. The extent to which such controls affect *A. hardii* depends on the size and intensity of the specific treatment and the amount of habitat affected within the range of the salamander. No specific studies have addressed these issues.

Climatic Changes

Scientists have long recognized climate, especially temperature and precipitation, as one of the major ecological forces affecting living organisms (LaRoe 1995). Over the next 60 years, significant changes in the patterns and abundance of precipitation are predicted, as well as an average increase in temperature of 5.4°F (Houghton et al. 1990). Currently, the Southwest (including the entire state of New Mexico) is enduring a multi-year drought. While there is evidence to suggest that global warming is influencing the distributions of some plants and animals elsewhere in the United States (LaRoe 1995), there is none to suggest that drought or global warming threaten *A. hardii* at this time. One consequence of global warming trends or drought could be the restriction of salamanders to the

higher elevations within their range, where more hospitable conditions might persist.

Conservation Status

Available evidence does not indicate that the distribution of the Sacramento Mountain salamander is either expanding or contracting within the three disjunct areas it inhabits. In the past 10 years, researchers have revisited some historical localities known from the 1950s and 1960s in the Sacramento and Capitan mountains and have continued to find salamanders (Meents 1987, Scott et al. 1987; C. Painter, pers. comm.). New localities from the Sacramento Mountains have been documented during this time, though most merely fill gaps within the current range and do not represent expansions. The abundance of localities known from the Sacramento Mountains (figure 1) most likely reflects this increased effort by researchers. There are considerably fewer localities from the White and Capitan mountains (figure 1). This is due to the relatively lower survey effort made here, as well as the difficulty of accessing the highest parts of these mountains due to rugged terrain, inadequate roads, or lack of roads; most of the salamander's habitat within the White and Capitan mountains is in designated wilderness areas and therefore roadless. Relatively large areas of mixed-conifer forest within the Mescalero Apache Indian Reservation represent an untapped reservoir for additional populations and future range expansions. The proximity to both the White and Sacramento mountain populations makes the area suitable as a potential corridor between neighboring populations. Small, disjunct populations are subject to extinction due to chance environmental and demographic events, and to loss of genetic variability from genetic drift. The potential for movements between nearby populations alleviates these problems and makes each small population part of a larger, more viable metapopulation.

Due to limitations of the available data, regional trends in salamander abundance cannot be assessed. The abundance of salamanders in the White and Capitan populations has not been thoroughly documented; the only long-term monitoring data come from the ongoing study of logging impacts on salamanders in the Sacramento Mountains. Similar studies should be initiated in other parts of the salamander's range, particularly in the Capitan and White mountains, preferably beginning before planned forest disturbances in order to assess the status of natural, undisturbed populations. Although data from the long-term study indicate that numbers of salamanders can fluctuate considerably over time on both disturbed and undisturbed sites, it is important to establish a baseline

reference for natural fluctuations in populations, against which changes resulting from perturbations can be compared. Post-disturbance data are most meaningful when they can be compared to pre-disturbance data. Survey methods should be standardized, and data on sex, size class, and reproductive status should be collected in addition to presence/absence information.

Because the Sacramento Mountain salamander is restricted to mixed-conifer forests primarily within the Lincoln National Forest, it is assumed that these forests are essential to the survival of the species, and that management actions (past, present, and future) on Forest Service land directly impact salamanders. Historical logging in the Sacramento Mountains was brief (lasting just over 40 years) and often intense, beginning at the turn of the century (Glover 1989; figure 4). The introduction of steam-powered trains and an extensive railroad system (running between Alamogordo and the Sacramento Mountains) coincided with intensive, mechanized logging over a large area of the mountains (Glover 1989). During this time,

portions of the Mescalero Apache Indian Reservation were logged, and to a lesser extent, the White and Capitan mountains. Historical timber harvest intervals were probably longer than today because of the more intensive cuts (clearcuts) made then.

The current 10-year Lincoln National Forest Plan indicates that logging will occur only within the range of the southernmost population of *A. hardii*, and that 88% (122,000 of 139,000 acres) of the timber will be managed using the even-aged system (U.S. Forest Service 1986:5). Immediate effects will include younger-aged stands, which will ultimately generate few or only small downed logs and less-extensive root systems. This may not be beneficial to the salamander, which seems to require a mix of young and old logs to ensure short- and long-term habitat components (Ramotnik and Scott 1988). At present, logging activities within occupied salamander habitat are complete and, in general, have complied with the management recommendations drafted by the New Mexico Salamander Working Group. The proposed timber harvest allotment



Figure 4. Mouth of Benson Canyon, Sacramento Mountains, Lincoln National Forest in June 1928. This intensely logged area was also impacted by fire and erosion. Photograph by E.S. Shipp.

of 15 million board feet per year in the 10-year Plan has not been met in recent years due to interim guidelines placing restrictions on logging in mixed-conifer forests within the range of the Mexican spotted owl. Standards and guidelines in the recent amendment to the 10-year plan (U.S. Forest Service 1996) and the impending revision of that plan will directly impact northern salamander populations. The emphasis in the recent amendment on uneven-aged management should provide long-term benefits by ensuring long-term habitat components such as older, larger logs, while enhancing short-term benefits via retention of snags and woody debris larger than 12 inches in diameter (figure 5).

Plethodontids depend on moisture, so they are vulnerable to activities that dry the habitat. Unlike aquatic plethodontids, which must seek open bodies of water for breeding, *A. hardii* is not dependent on permanent water sources; therefore, it is not subject to environmental stresses such as ultraviolet radiation or high acidity levels, which may be partially responsible for declining amphibian popu-

lations elsewhere in the West (Blaustein et al. 1994). Logging results in dry surface conditions and appears to be the primary human-caused threat to the Sacramento Mountain salamander. Given that logging (sometimes intense) occurred within a large part of the historical range of the salamander, some areas were likely made inhospitable to salamanders. Although historical population levels are unknown, it is apparent that the salamander has endured some level of logging activities over the past 60-90 years. Whereas data indicate that logging reduces populations of Sacramento Mountain salamanders in some areas (Ramotnik 1996), there is no evidence that logging has eliminated any populations.

The consequences of large-scale, intense fires within the range of the Sacramento Mountain salamander also can negatively impact these amphibians. However, fires are generally infrequent at higher elevations, where generally cooler and moister conditions diminish flammability. Historically fires probably occurred more frequently but at lower intensities in the Sacramento Mountains than they



Figure 5. Photograph taken in 1908 of a section of the "Cloudcroft Reserve" (Lincoln National Forest) that has never been logged (note the large-diameter coniferous tree to the left and the dense undergrowth). Upon decay, large trees will provide long-term habitat components for Sacramento Mountain salamanders. Photographer unknown, 15 May 1908.

do today due to the decades-old trend of fire suppression by land management agencies. This suppression has left an explosive legacy on western lands during the 20th century. Fire behavior, as well as its impact on *Aneides*, may be difficult to predict in the immediate future as fuel loads continue to build, creating opportunities for large catastrophic fires.

Based on available information, populations of the Sacramento Mountain salamander appear to be relatively secure under current management practices. The distribution of the salamander appears to be consistent with that of its historical range, while populations to the south, which have received more attention than those elsewhere, seem to be locally abundant and widespread at appropriate elevations. Those to the north occur primarily in designated wilderness and thus receive some level of protection. Habitat association with the Mexican spotted owl will likely be beneficial to *Aneides*, so long as the owl's protective status remains.

Whereas there appears to be no crisis relative to the conservation of the salamander, we know that the species is sensitive to certain habitat changes resulting from management activities. A conservation strategy is needed in order to ameliorate these actions and to develop a coordinated approach for salamander conservation. The Lincoln National Forest Plan covering the next 10-15 years will have important ramifications for *Aneides* relative to logging expectations and schedules, logging intervals, and slash disposal. Significant changes during the next planning period could include logging just outside the Capitan Mountains and White Mountain wilderness areas, which were last logged in 1980 and 1964 before they were closed to logging by wilderness designation. The future direction for the management of the Sacramento Mountain salamander on the Lincoln National Forest could depend on what we have learned from consequences of our past management actions within the range of the salamander.

Research Needs

Many aspects of the basic biology and natural history of *A. hardii* remain to be ascertained. A large gap exists in our understanding of the importance of the subterranean environment to the salamander, resulting in uncertainty in our ability to accurately estimate population size. Traditional methods of surveying for terrestrial salamanders are more appropriately referred to as surface censuses, in that they include turning over surface objects such as logs, rocks, and coarse woody debris. These methods are convenient for researchers but may be inappropriate for determining densities when not all individuals are present on the surface during the survey. Studies by Taub (1959,

1961) and Test and Bingham (1948) showed that the majority of plethodontid salamanders occur beyond the accessible reaches of the surface, and that we are greatly underestimating population size. More recently, Fraser (1976) determined that some species of plethodontid salamanders make vertical movements in response to dry surface conditions, so that surface densities of salamanders are reduced as moisture decreases. If the subterranean habitat is the primary site for egg deposition, and the majority of salamanders move belowground when surface conditions are inhospitable, then we are likely underestimating population size when we conduct surface counts during dry conditions. We should strive to improve the methodology used to "count" salamanders so that variance estimates around a population estimate are available, allowing for some "confidence" in the estimates. We also need to decide whether we need to know absolute numbers of the total population, or relative abundance of the surface population.

If the subterranean element is an important component of the salamander's environment, we need to understand how they access it and how deep they must go to avoid lethal temperatures. An examination of soil pits dug in a variety of habitats within the Sacramento Mountains indicates that the only apparent routes to these depths are rotted-out root channels (Scott and Ramotnik 1992). If salamanders use decayed roots as access points to the subsoil, it is important to know at what age a tree produces roots large enough for a salamander to pass through once the roots have decayed. How will the lag-time in changing from even- to uneven-aged management impact salamanders? What effect does heavy equipment have on soil compaction? Is compaction sufficient to destroy passageways, such as decayed root channels, thus impeding salamander movement to the subsurface? Additional studies are needed to address these management issues with respect to logging intervals and soil compaction.

We still do not understand the relationship of large logs and salamander abundance. We know that salamanders are often found within and under the bark of large logs, and that all of the egg clutches to date have been found within large logs. It is possible that these logs are just a convenient place to find salamanders, because in areas where logs are absent, salamanders are found beneath rocks (N. Scott, pers. comm.). Can large logs provide winter refugia for salamanders, and if so, how does snow cover affect log temperature? Once large logs have decomposed, eliminating potentially important microhabitats for foraging and nesting, will salamanders disappear? If large logs serve these functions, we should be prepared to adjust management efforts in order to maintain a mix of young and old logs to ensure both short- and long-term components of the habitat.

The ability of salamanders to recolonize disturbed habitats is another area where data are lacking. We do know

that salamanders move short, horizontal distances within a log under dry conditions and make larger moves across the ground surface under wet conditions. How easily can they make longer moves to escape large disturbed areas, particularly during extended periods of drought? Can they find enough food to offset the metabolic costs of increased locomotor activities? Can they do so only when it rains, or only at night when the humidity is high? Can salamanders use corridors? And if so, what size should they be? Salamanders cannot always wait out extended periods of environmental stress but must return to the litter to forage where prey are most abundant. Their long-term survival will depend on their ability to escape inhospitable conditions and migrate to more optimal sites.

We need to begin monitoring salamander populations in the White and Capitan mountains to establish population trends, and to continue to monitor populations, particularly those from the long-term logging study. An analysis of the distribution of salamander size classes from this study is needed to determine if the pattern of fewer juveniles on logged sites is real, or merely a sampling artifact.

Finally, we need to continue defining the range of the Sacramento Mountain salamander while looking for additional populations. A survey of Carrizo Peak was conducted in August 1988, but no salamanders were detected despite the presence of seemingly good habitat at the peak (2943 m; Scott and Ramotnik 1989). This area should be reexamined under favorable (wet) conditions, and additional regions in the southern part of the state should be periodically surveyed for salamanders. New populations will provide another level of security for the current populations while increasing genetic variability of metapopulations. The work of Pope and Highton (1980) on genetic variation of metapopulations should be continued. Because they collected only single samples from each of three mountain ranges, the extent of within-isolate variation is unknown and warrants further study.

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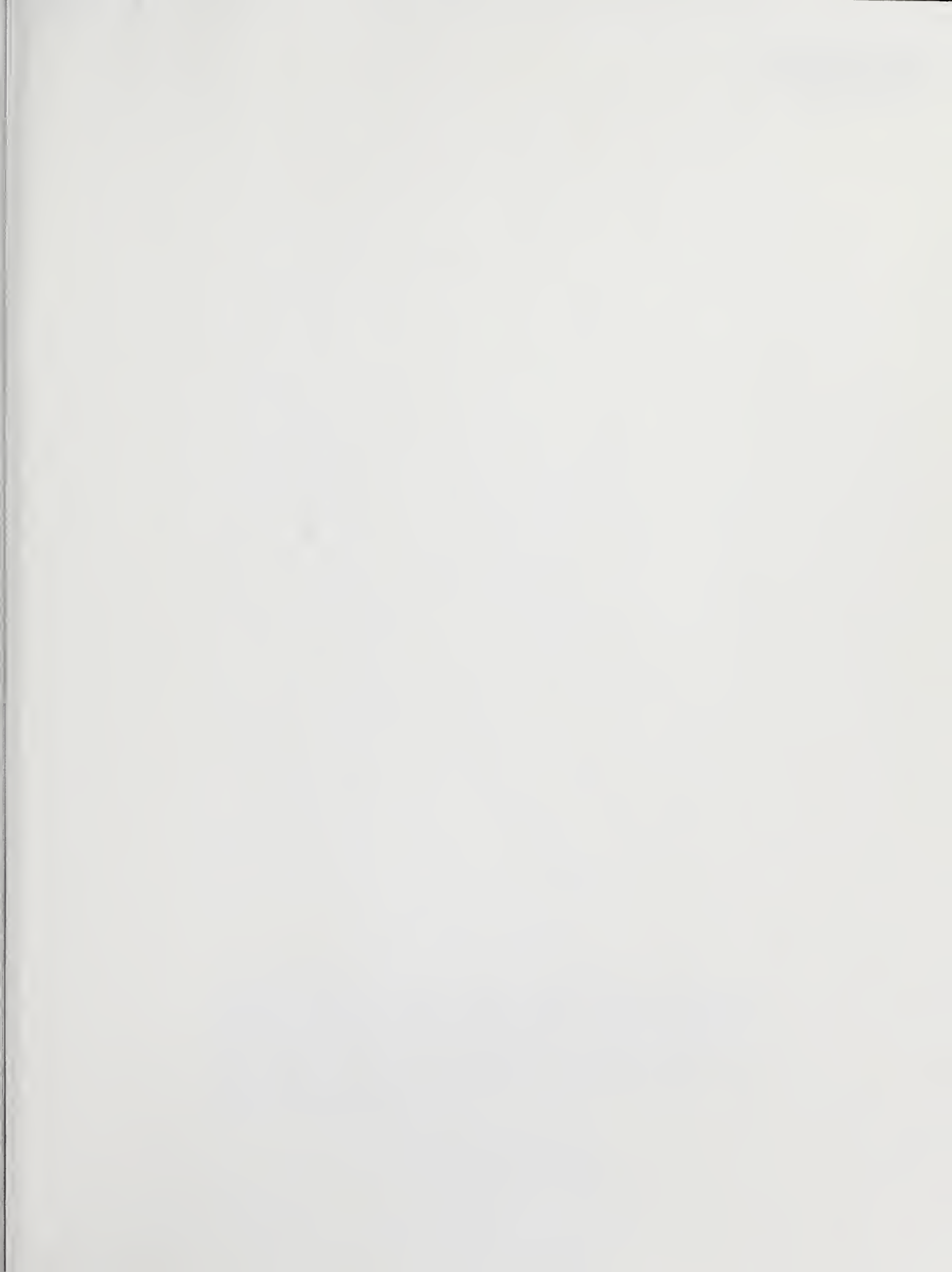
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